# PDF's for the LHC: LHC cross section benchmarking

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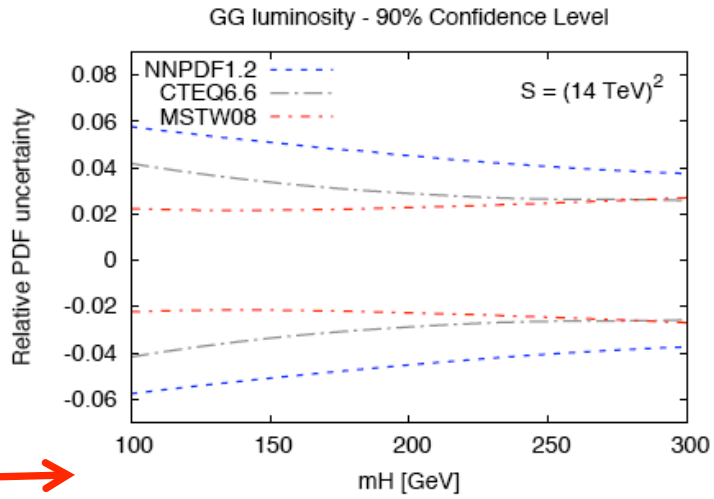
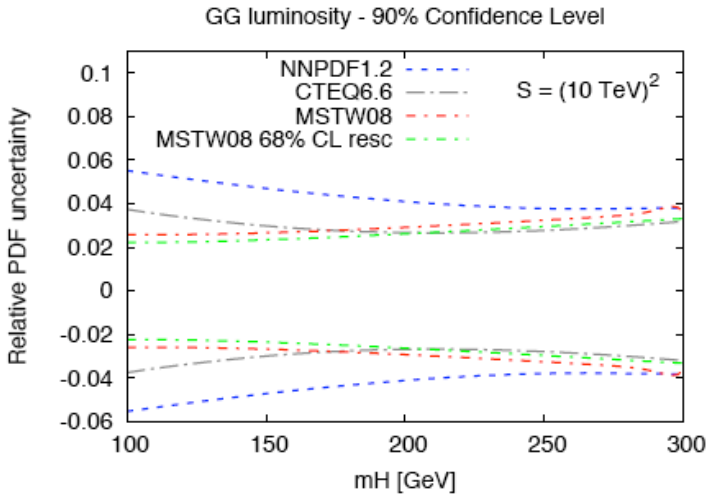
# …but first, a brief introduction

- The calculation of PDF uncertainties for LHC cross sections is becoming more topical, as LHC exp cross sections themselves are more topical
- The LHC experiments have gone/are going through exercises tabulating important cross sections and their uncertainties
- In many cases, the estimates of cross sections and uncertainties from the PDF groups (such as CTEQ, MSTW, NNPDF…) are closer than many people thought
- A discussion, started at Les Houches, was formalized within the PDF4LHC working group to perform some benchmarking tests to understand the commonalities and differences between the predictions and uncertainties of the different PDF groups
- First comparisons in meeting (Mar 26) of PDF4LHC

see for example, A. Vicini's talk at the Jan. 29, 2010 PDF4LHC meeting



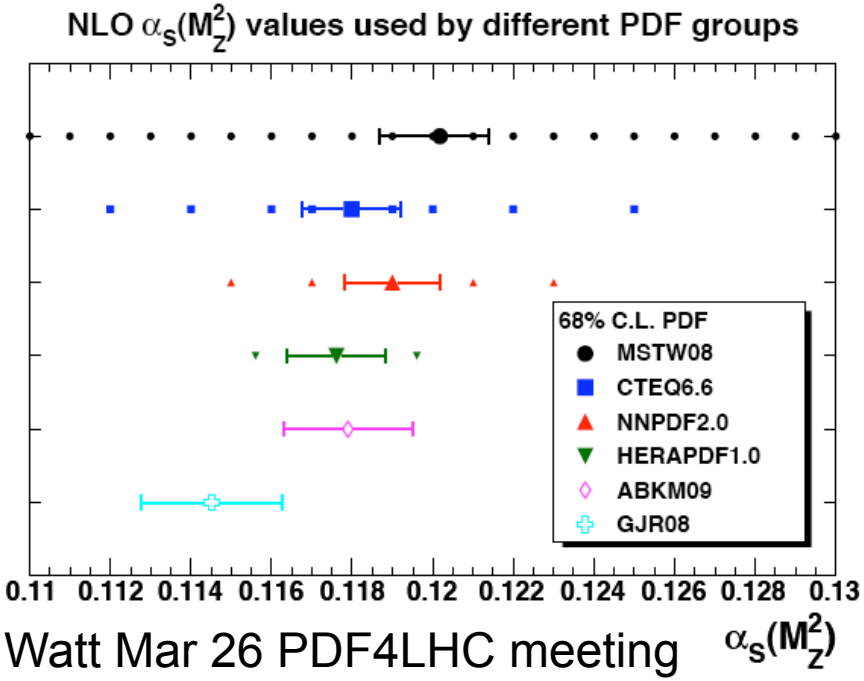



# PDF errors

- So now, seemingly, we have more consistency (at least in some cases) in the size of PDF errors
- The eigenvector sets (or NNPDF equivalent) represent the PDF uncertainty due to the experimental errors in the datasets used in the global fitting process
- Another uncertainty is that due to the variation in the value of $\alpha_s$
- MSTW has recently tried to better quantify the uncertainty due to the variation of $\alpha_s$, by performing global fits over a finer range, taking into account correlations between the values of $\alpha_s$ and the PDF errors
- …more recent studies by CTEQ and NNPDF as shown in the talks in the PDF4LHC meetings, and in Les Houches writeup

# $\alpha_s(m_Z)$ and uncertainty

- Different values of $\alpha_s$ and of its uncertainty are used
- CTEQ and NNPDF use the world average (actually 0.118 for CTEQ and 0.119 for NNPDF), where MSTW2008 uses 0.120, as determined from their best fit




- Latest world average (from Siggi Bethke->PDG)
  - $\alpha_s\ (m_Z) = 0.1184$ +/- 0.0007
- What does the error represent?
  - Siggi said that only one of the results included in his world average was outside this range
  - suppose we say that +/-0.002 is a reasonable estimate of the uncertainty

# $\alpha_s(m_Z)$ and uncertainty

- Could it be possible for all global PDF groups to use the world average value of $\alpha_s$ in their fits, plus a prescribed 90% range for its uncertainty (if not 0.002, then perhaps another acceptable value)?
- For the moment, we try determining uncertainties from $\alpha_s$ over a range of +/- 0.002 from the central value for each PDF group; we also calculate cross sections with a common value of $\alpha_s$=0.119 for comparison purposes

# (My) interim recommendation for ATLAS Higgs

- Cross sections should be calculated with MSTW2008, CTEQ6.6 (and NNPDF)
- Upper range of prediction should be given by upper limit of error prediction using prescription for combining $\alpha_s$ uncertainty with error PDFs
  - in quadrature for CTEQ6.6
  - using eigenvector sets for different values of $\alpha_s$ for MSTW2008
  - (my suggestion) as standard, use 90%CL limits
- Ditto for lower limit
- So for a Higgs mass of 120 GeV at 14 TeV, the gg cross section lower limit would be defined by the CTEQ6.6 lower limit (PDF+$\alpha_s$ error) and the upper limit defined by the MSTW2008 upper limit (PDF+$\alpha_s$ error)
  - with the difference between the central values primarily due to $\alpha_s$
- One of the purposes of this benchmarking exercise is to see if we can come up with a universal prescription for calculating the uncertainty
- …which would go into a PDF4LHC writeup

# PDF Benchmarking Exercise 2010

- Benchmark processes, all to be calculated

  (i) at NLO (in MSbar scheme)

  (ii) in 5-flavour quark schemes (definition of scheme to be specified)

  (iii) at 7 TeV [ and 14 TeV]  LHC

  (iv) for central value predictions and +-68%cl [and +- 90%cl] pdf uncertainties

  (v) and with +- $\alpha_s$ uncertainties

  (vi) repeat with $\alpha_s(m_Z)=0.119$

  (prescription for combining with pdf errors to be specified)

- Using (where processes available) MCFM 5.7
  - gzipped version prepared by John Campbell using the specified parameters and exact input files for each process (and the new CTEQ6.6 $\alpha_s$ series)->thanks John!
  - sent out on first week of March (and still available to any interested parties)
  - statistics ok for total cross section comparisons

# Cross Sections

1. $W^+$, $W^-$, and Z total cross sections and rapidity distributions total cross section ratios $W^+/W^-$ and $(W^+ + W^-)/Z$, rapidity distributions at y = -4,-3,...,+4 and also the W asymmetry: A_W(y) = $(dW^+/dy - dW^-/dy)/(dW^+/dy + dW^-/dy)$ using the following parameters taken from PDG 2009
   - $M_Z$=91.188 GeV
   - $M_W$=80.398 GeV
   - zero width approximation
   - $G_F$=0.116637 X $10^{-5}$ $GeV^{-2}$
   - other EW couplings derived using tree level relations
   - BR(Z-->ll) = 0.03366
   - BR(W-->lnu) = 0.1080
   - CKM mixing parameters from eq.(11.27) of PDG2009 CKM review

$$V_{CKM} = \begin{pmatrix} 0.97419 & 0.2257 & 0.00359 \\ 0.2256 & 0.97334 & 0.0415 \\ 0.00874 & 0.0407 & 0.999133 \end{pmatrix}$$

   - scales: $\mu_R = \mu_F = M_Z$ or $M_W$

# Cross Sections

## 2. gg->H total cross sections at NLO

- $M_H$ = 120, 180 and 240 GeV
- zero Higgs width approximation, no BR
- top loop only, with $m_{top}$ = 171.3 GeV in sigma_0
- scales: $\mu_R = \mu_F = M_H$

## 3. ttbar total cross section at NLO

- $m_{top}$ = 171.3 GeV
- zero top width approximation, no BR
- scales: $\mu_R = \mu_F = m_{top}$

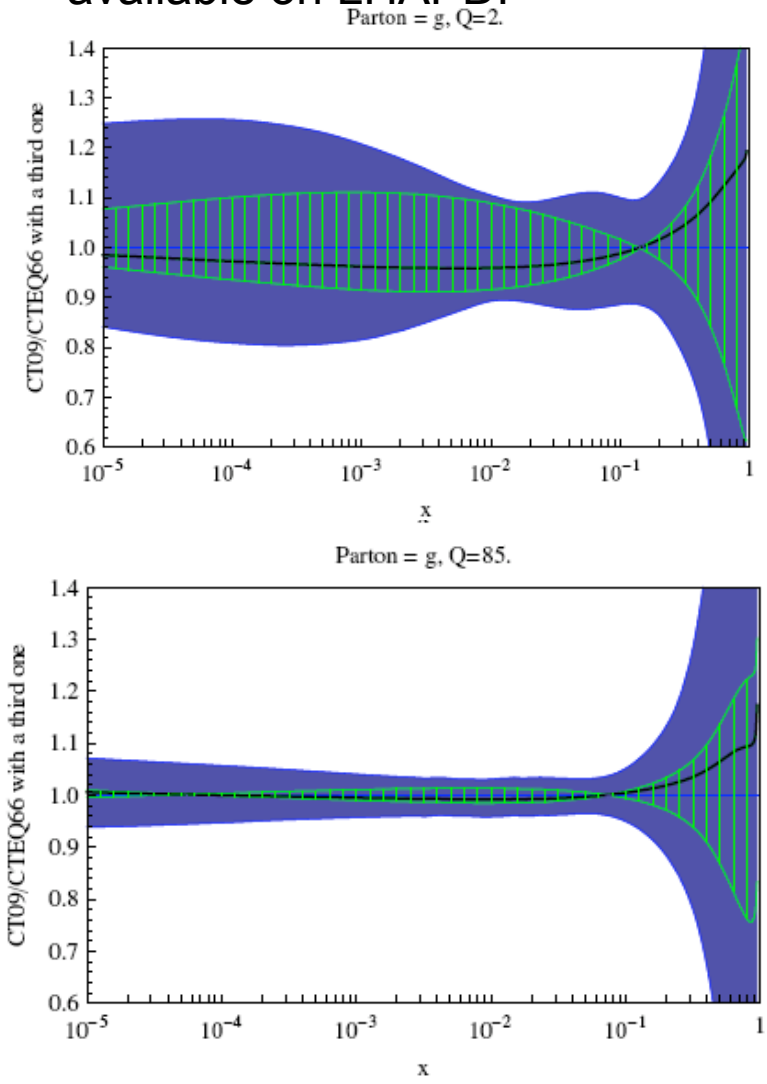
# The following are optional

4. inclusive jet cross section distribution at NLO
   - use FastNLO "fnl0004" option with sqrt(s) = 14 TeV, D=0.7 $k_T$ algorithm
   - jet rapidity bin: $0 < |y_J| < 0.8$
   - scales: mu_R = mu_F = $p_T^J$
5. Drell-Yan NLO dsigma /dM dy at y=0 for e.g. M = 7 and 14 GeV
   - scales: mu_R = muF = M
   - coupling = alpha_em(0) = 1/137.036

# For CTEQ: $\alpha_s$ series

- Take CTEQ6.6 as base, and vary $\alpha_s(m_Z)$ +/-0.002 (in 0.001 steps) around central value of 0.118
- Blue is the PDF uncertainty from eigenvectors; green is the uncertainty in the gluon from varying $\alpha_s$
- We have found that change in gluon due to $\alpha_s$ error (+/-0.002 range) is typically smaller than PDF uncertainty with a small correlation with PDF uncertainty over this range
  - as shown for gluon distribution on right
- Because of this small correlation, PDF error and $\alpha_s$ error can be added in quadrature
- So the CTEQ prescription for calculating the total uncertainty (PDF +$\alpha_s$) involves the use of the 45 CTEQ6.6 PDFs and the two extreme $\alpha_s$ error PDF's (0.116 and 0.120)
- See Pavel's talk

paper in preparation: $\alpha_s$ sets available on LHAPDF



# Higgs cross sections and uncertainties

- Linear dependence of Higgs cross section at NLO with $\alpha_s$ can be observed
- $\alpha_s$ and gluon distribution are anti-correlated in this range, but the Higgs cross section has a large K-factor (NLO/LO), so $\alpha_s$ dependence from the higher order contribution
- Predictions are from new CTEQ paper; not exactly the same setup as for MCFM benchmark predictions, so numerical values aren't identical, but linear $\alpha_s$ dependence is clear

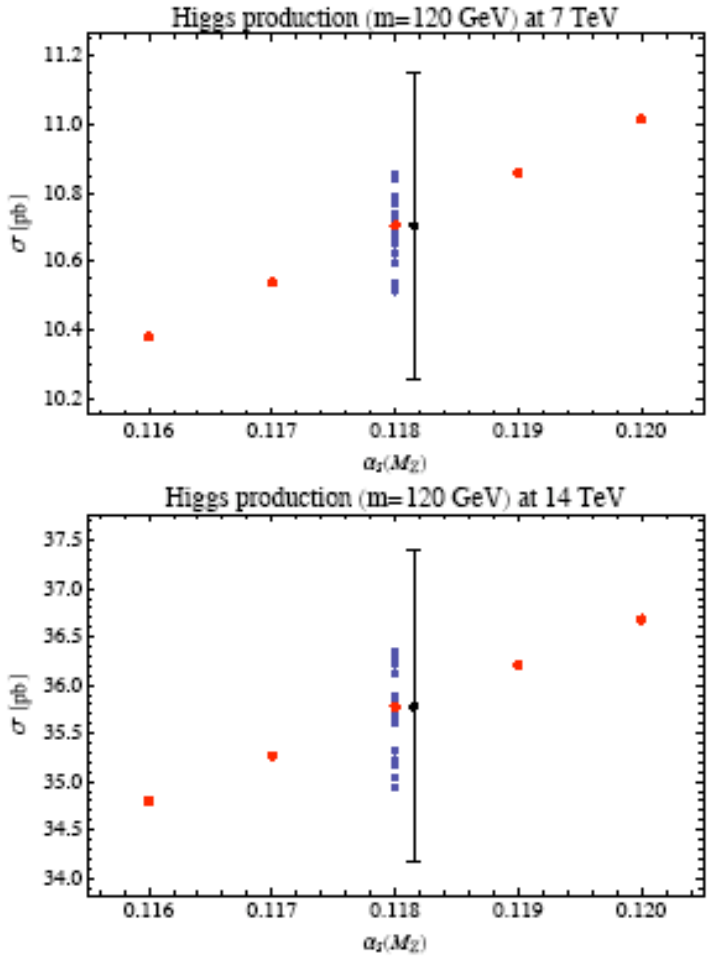



Figure 7: Cross section for Higgs production (mass = 120 GeV) at the LHC, with center of mass energy 7 TeV and 14 TeV, as a function of $\alpha_s(M_Z)$. The predictions for the 45 alternative PDF sets are shown for $\alpha_s(M_Z) = 0.118$. For the other values of $\alpha_s(M_Z)$ (= 0.116, 0.117, 0.119, 0.120) only the central prediction is shown. The combined uncertainty range (CTEQ6.6+CT66AS) is shown as the error bar; cf. Table 1.

# Exact treatment

- Comparison of PDF errors when adding in quadrature compared to exact treatment

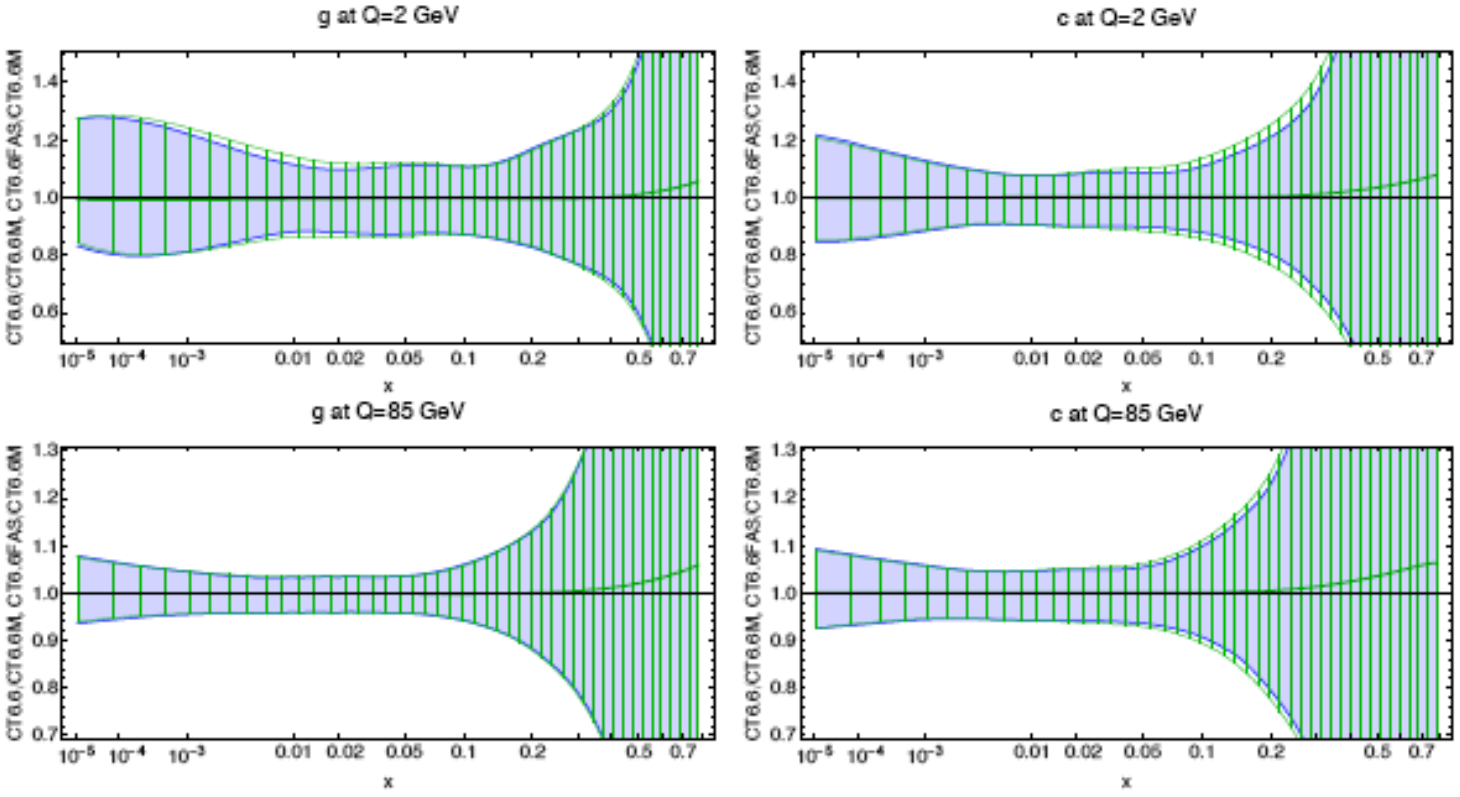



Figure 5: Comparison of CT66FAS uncetrtainty bands and CTEQ66+CT66AS uncertainty bands, normalized to the standard CTEQ6.6 fit, for gluon and charm PDFs at $Q = 2$ and 85 GeV.

very nice discussion of quadrature treatment in new CTEQ paper

# Correlations

- Correlation cosine: defines degree of correlation between two quantities

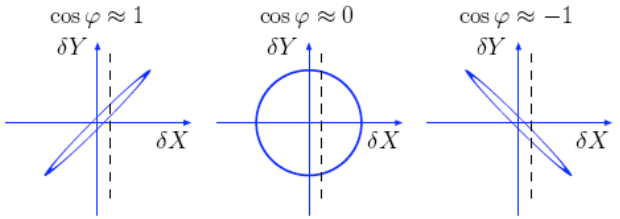
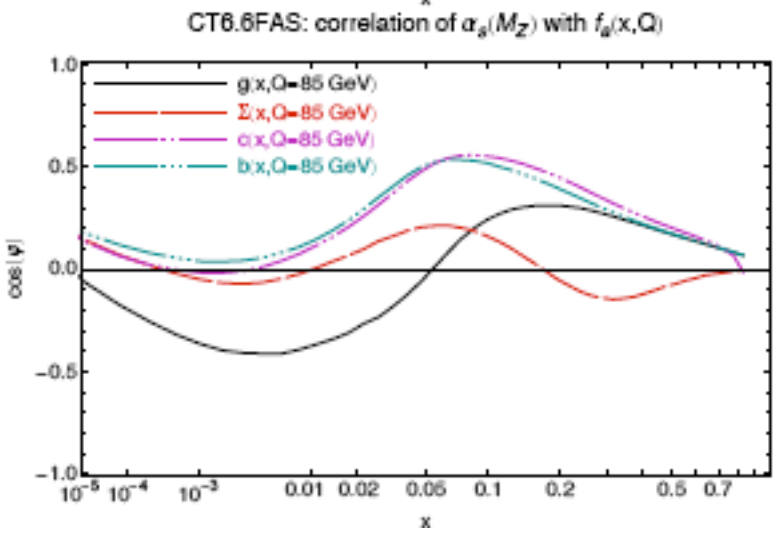
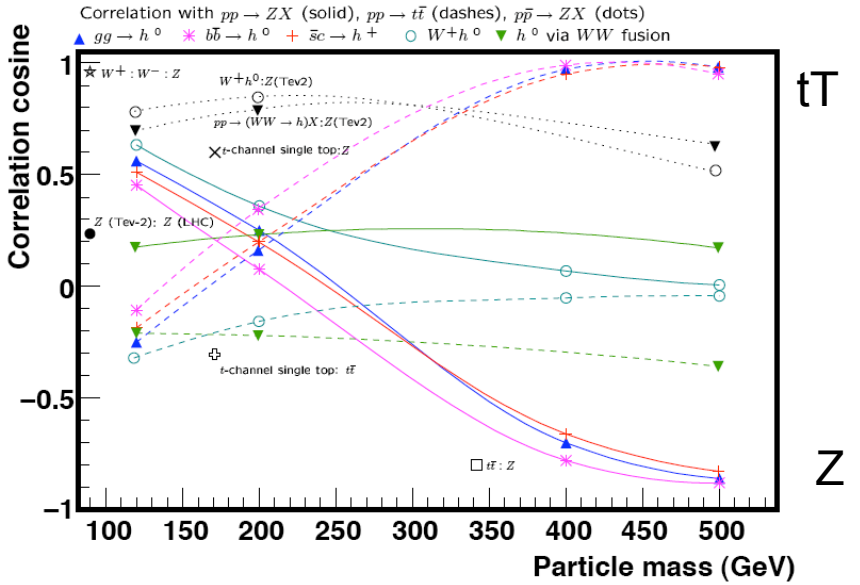



Figure 1: Dependence on the correlation ellipse formed in the $\Delta X - \Delta Y$ plane on the value of the correlation cosine $\cos\varphi$.

- Below is cosine for different PDFs, including the gluon distribution with $\alpha_s$



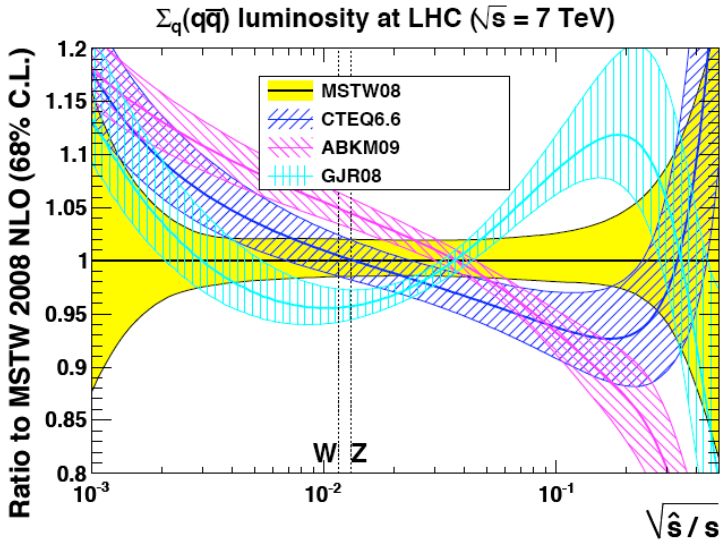

- Also useful to examine correlations between cross sections, as shown below for 14 TeV

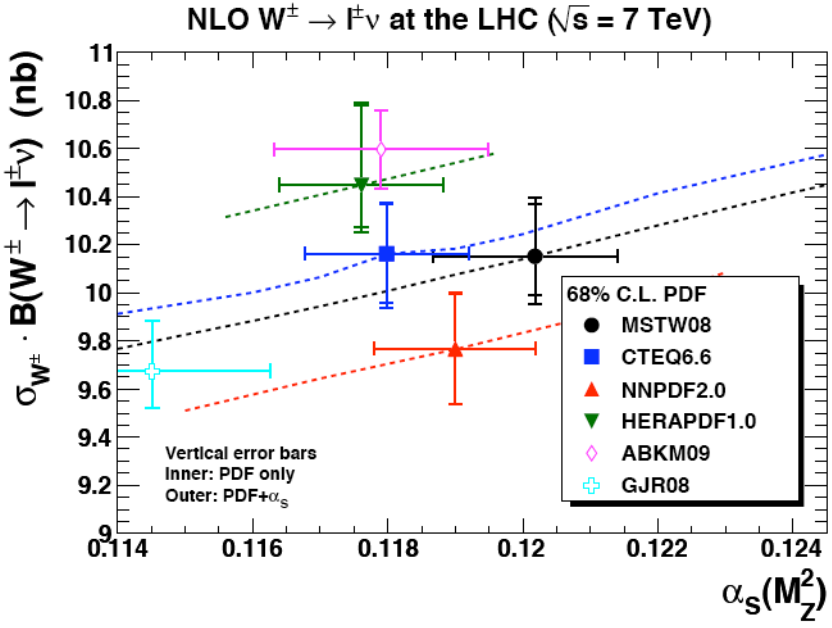



- Will expand this further for 7 TeV

# Some results from the benchmarking

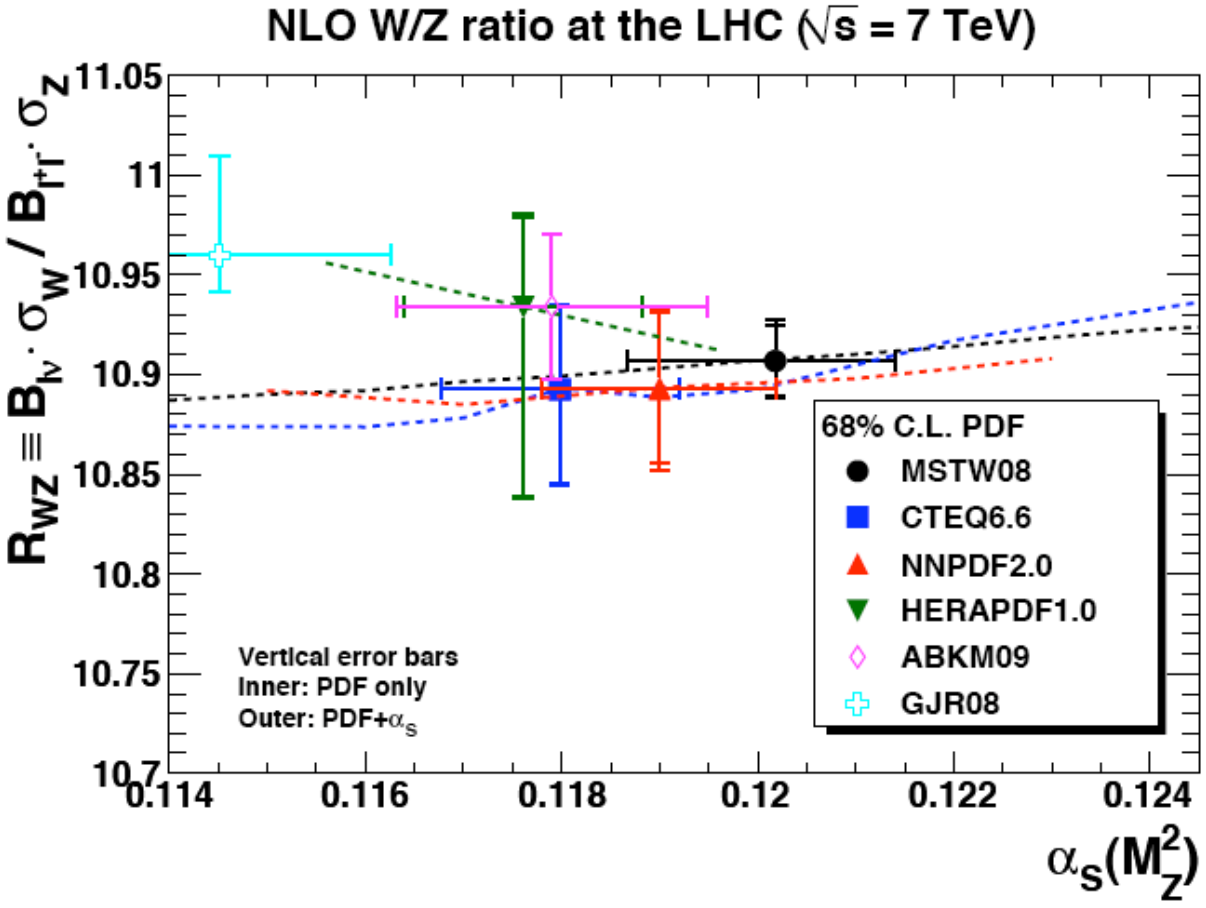
- …from G. Watt's presentation at PDF4LHC meeting on March 26
- See also S. Glazov's summary in the March 31 MC4LHC workshop at CERN
- CTEQ/MSTW predictions for W cross section/uncertainty in very good agreement
  - small impact from different $\alpha_s$ value
  - similar uncertainty bands
- NNPDF prediction low because of use of ZM-VFNS
- HERAPDF1.0 a bit high because of use of combined HERA dataset



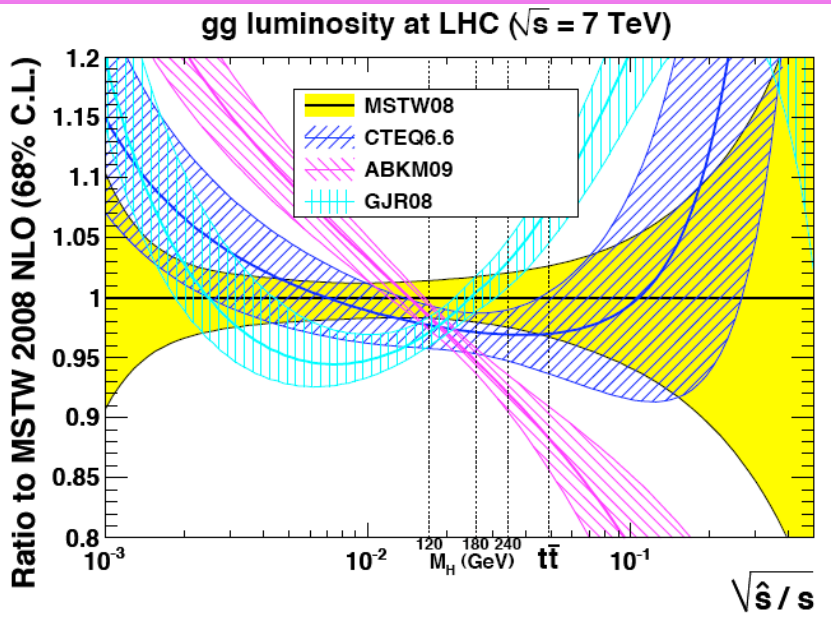
# W/Z ratio

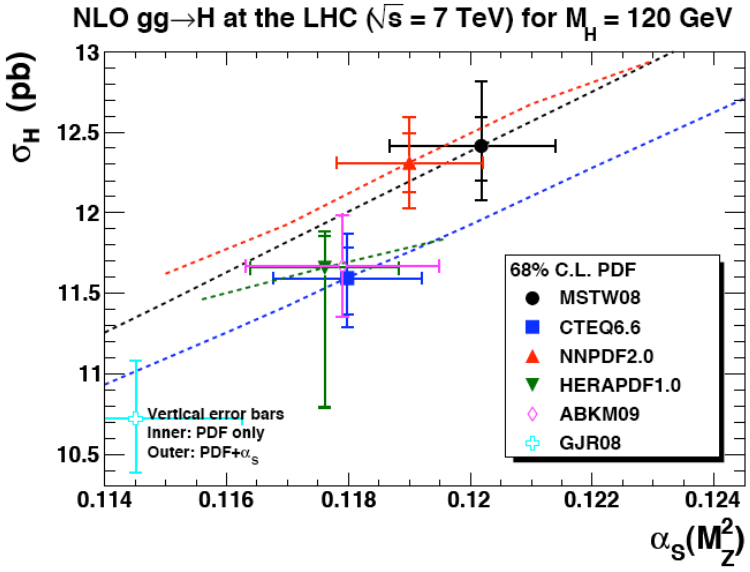
- Good agreement among the PDF groups



# Some results from the benchmarking

- …from G. Watt's presentation at PDF4LHC meeting on March 26
- Similar gluon-gluon luminosity uncertainty bands, as noted before
- Cross sections fall into two groups, outside 68% CL error bands
- But, slide everyone's prediction along the $\alpha_s$ curve to 0.119 (for example) and predictions agree reasonably well
  - within 68% CL PDF errors



# Summary

- PDF4LHC/Les Houches benchmarking exercise has provided useful understanding of commonalities/differences among the different PDF groups
  - and hopefully we can continue towards more standardization
- Benchmark cross sections will be made available in a reference document, with predictions from all participating PDF groups
  - see https://wiki.terascale.de/index.phptitle?=PDF4LHC_WIKI
- …and recommendations on how to estimate PDF/$\alpha_s$ uncertainties for LHC cross sections where such uncertainties are *critical/non-critical*
- gg->Higgs is one case for NNLO corrections are large, so NNLO cross sections are necessary
- Available from only a few groups to date
- Since most of the impact arises from the matrix element and not the change in PDF's, I've suggested providing *approximate* NNLO predictions in cases where NNLO PDFs are not available
  - NNLO ME + NLO PDF